The first prototype of SSD for the AugerPrime project

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The Pierre Auger Observatory has begun a major Upgrade (AugerPrime). AugerPrime, for the project management of which the Lecce group is responsible, will be upgraded with new scintillation detectors for a more detailed measurement of gigantic air showers. These new scintillation detectors will be assembled and tested in parallel in multiple assembly facilities, from which Lecce. We describe the assembly and test of the first muon detector prototype for the Pierre Auger Surface Detector upgrade performed in Lecce.

1. Introduction

The approved Auger upgrade program foresees a complementary measurement of the shower particles through a plastic scintillator plane placed above the existing Water-Cherenkov Detector (WCD)[1,2]. The shower will then be sampled with two different detectors having different responses to muon and electromagnetic particles.
The design chosen consists of a detector based on a plane of plastic scintillator (composed by two modules) and read out in an integral way using only one photodetector (PMT). The dynamic range of the unit has to be adequate to guarantee the physics goals of the upgrade. The detector will be assembled and tested in parallel in multiple assembly facilities in order to reduce the production time. Part of the production work will be done in Lecce.
Before starting the production phase and in order to define the preproduction procedure, each of the assembling facilities has built a prototype of the SSD detector. Here we describe the prototype assembled in Lecce.

2. SSD Detector Design

The Surface Scintillator Detector (SSD) basic unit consists of two modules of 2 m^2 extruded plastic scintillator read out by wavelength-shifting (WLS) fibers coupled to a single photomultiplier. The active part of each module is a scintillator plane made by 24 bars 1.6 m long of extruded polystyrene scintillator produced by Fermi National Accelerator Laboratory (FNAL). Each bar is 1 cm thick and 5 cm wide. The scintillator bars are co-extruded with a TiO_2 outer layer for reflectivity and have four holes in which the fibers can be inserted. The light produced in the scintillator is collected with optical fibers (Kuraray Y11 300) and carried to one PMT. At both ends of the scintillator plane there are routers, made by extruded polystyrene, with grooves having a "U"configuration. The routers have been designed with curvature radii of 5 cm and this, together with the "U"shape, means that each fiber passes from one hole of a scintillator bar to one hole of the neighbor bar. The curvature radii and the grooves allow mechanical stability in order to avoid the fiber breaking during the operation. The fibers are cut all at the same length and in the internal part of the SSD they are forced to follow grooves with a "snake"shape from the bars to the PMT. In this configuration the fibers are read out from both ends. In Fig. 1 the central part of the SSD is shown. It is possible to recog-

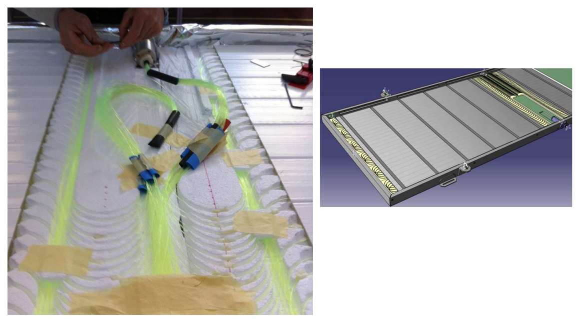

Figure 1. Left: routers with the snake shape in the central part of the detector. The fibers connected to the PMT are from LUNA module. Right: technical design of the SSD. The scintillator and the routers are visible.

Figure 2. Complete view of the two module, LUNA and TERRA, before closing the detector.

nize the grooves with the “snake”shape used to drive the fibers from the bars to the PMT.

3. The Lecce Prototype

Due to the fact that neither the scintillator bars nor the optical fibers were available, to assembly the prototype we have recycled the scintillator bars and fibers of the two TOSCA prototypes realized in Torino. Therefore the SSD prototype assembled in the Lecce laboratory has one module realized with 12 scintillator bars 1.6 m long, 1 cm thick and 10 cm width with 4 holes (LUNA module) and one module realized with 24 scintillator bars having the same length, 2 cm thickness and 5 cm width (TERRA module). In this case only two holes are present on each bar. Fig. 2 shows the two modules before closing the detector. In foreground the 10 cm wide bars are visible, while in background the 5 cm wide bars. The optical fibers are the ones used in the TOSCA prototypes (Kuraray Y11 200). Due to the different bars dimensions, we decided to test only one module at a time. We connect the fiber bundle to the PMT via a SAINT-GOBAIN optical grease (BC630). Although we consider that the silicon pad (SAINT-GOBAIN BC634A) warranty a more efficient operation, we have used at this stage only the optical grease.

4. PMT and cookie

The fiber bundle terminations from the two modules are inserted in a PVC cylinder and glued using the optical cement POLYTEC 601. In Fig. 1 it is possible to see that only the fiber bundle from one module (LUNA) has been packaged and optically connected to the PMT. This is hosted in an aluminum cylinder designed for darkness isolation of the vessel and for outer cabling. In Fig. 3, we show how the fiber bundle termination is realized before the coupling with the PMT. Fig. 3:top-left, all the fibers are inserted inside the PVC cylinder, positioned vertically on a support, and the optical cement is cast into the cylinder. Fig. 3:top-right shows the cylinder/fibers assembly after the cement drying. At this point we use a custom mechanical flange, realized in Lecce, to hold the drilling machine in order to cut the fiber bundle (Fig. 3:bottom-right). Moreover a custom mechanical arm, hooked to the vessel, holds in place the fiber bundle. Fig. 3:bottom-left shows a mock up of the fiber bundle after the cut and without the PVC cylinder. Fig. 4 shows the mechanism that allows the PMT/fibers coupling and the correct positioning of the PMT inside the detector vessel together with the outer connection.

Figure 3. Sequence showing the bundle fiber polishing process.

Figure 4. Mechanical structure for the PMT/fibers coupling and the correct positioning of the PMT inside the detector vessel together with the outer connection.

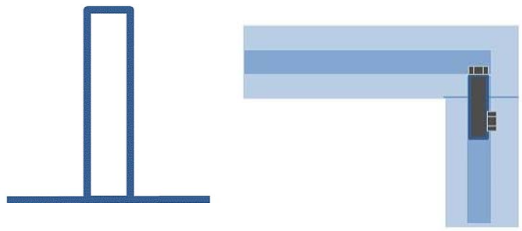

Figure 5. Sketch of the lateral bars used in the Lecce prototype (left). Schema of the corners connection (right.

Figure 6. Details of the external frame of the Lecce enclosure during the assembling phase.

The baseline SSD PMT is the HAMAMATSU R9420, head-on type, 8 stage with a 38 mm bialkali photochatode. This PMT shows good quantum efficiency at the wavelength of interest (in the green region) associated with an excellent linearity range (through a proper tapered ratio divider) of up to 200 mA of anode peak current.

5. The Enclosure

The enclosure assembled in Lecce is based on the design presented in the AugerPrime PDR[2]. Anyway several modifications have been implemented to the original design in order to solve some of the problems arised during the construction and assembling phase. The original design in the PDR is based on aluminum "I" bars forming the external frame of the box. In the realized prototype we have used the "I" bars with composed bars that combine a rectangular pipe with a thinning bars that can be used to support the internal components of the detector, to attach the module to support structure and to move the module during the deployment phase. In Fig. 5 (left) is shown a sketch of the bar proposed. The original "I" bars solution has not been adopted given the difficulty to realize the corners of the external frame, and in order to raise the insulation between the internal volume and the external enviroment.

The proposed bars (see fig 5) create a clear separation between the internal volume and the external environment, moreover give the possibility to fix the internal elements of the detector to the bars without breaking the external skin of the module. While for the final design we suggest to weld the proposed bars in the corners, in the current prototype we have just connect the bars without a 45 degree cut using a internal aluminum block to fix togheter the two bars (see fig 5 right). With this solution we do not see in our prototype an environmental light signal. This shows that the Lecce bars simplify the frame construction and reduce the complexity of the design. While in the prototype the Lecce bars are obtained combining two different elements (a rectangular pipe and a flat bar) for the production we suggest to produce the bars like they are with an extrusion process. The estrusion is cheaper and gives the posibility to add at the profile in any possible other facility. In fig 6 are visible some picture of the realized external frame of the Lecce prototype.

To support the scintillator bars and create the bottom skin of the module we have used panel of composed material following the indication given in the Nikhef design. The composed material (see fig **??**) has been glued to the external frame bars with araldite 2031. The gluing process is extremely fast and simple.

Before the assembly of the external frame with the Lecce bars in the center of one of the two longer sides we have realized the PMT access hole (see fig 7). To permit the insertion of the support for the PMT inside the module the bottom sendwich pannel has been cut.

To close the module we have used a second sandwich panel to fix the scintillator in position and guarantee the possibility to ship and install the module. The sandwich panel is fixed in position thanks to lateral support that are attached to the external frame. The use of a rectangular pipe

Figure 7. The PMT access point in the external frame of the enclusure

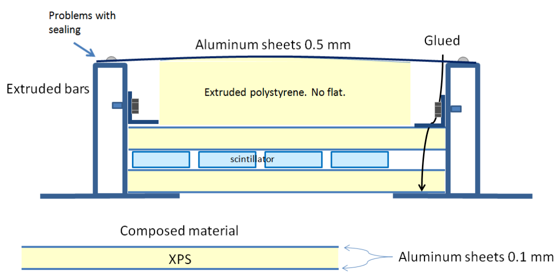

Figure 8. The design of the current enclosure of the Lecce prototype

for the frame permit to fix the supports without break the external skin of the module. The module, finally, is closed with a block of polystyrene and with a thin skin of aluminum that is fixed with rivet to the bars (see figure 8). In the prototype in Lecce we still do not have fixed the aluminum skin because we want to easily open and close the module for testing.

The developed solution is not totally satisfactory. While the curved polystyrene support the thin sheet of aluminum and intrinsically guarantee the not accumulation of the water in the center of the module, it create tension on the rivets. Moreover it is evident that a glue or a gasket is necessary to isolate the internal volume of the module from the external environment. We plan to test a different solution that use some of the ideas and technique developed by the Nikhef group. The ideas is to use a cover that has the double role of taking in position the scintillators and at the same time close the module. The method proposed permits also to open the module if necessary. The proposed design is presented in 10. The cover is realized with a sandwich panel identical to the bottom one glue to a frame. This cover reproduce the bottom structure making the module symmetric. At the top a sheet of aluminum is added to avoid the possibility that water or other material will accumulate in the center of the module. The aluminum sheet can be precurved or flat. The cover will be attached to the main structure with rivets.

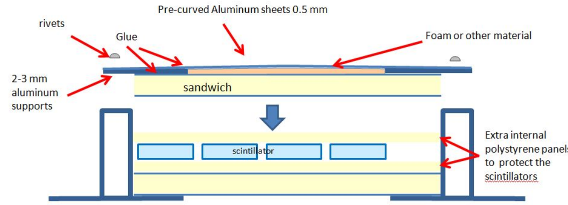

Figure 9. The evolution of the enclosure for the Lecce prototype

6. The PMT enclosure

To insert and easily extract the PMT from the module a specific design has been developed. In figure 7 is visible the access point for the PMT. The enclosure of the PMT is constituted of three main parts: an external aluminum cylinder, an internal plastic enclosure and the PMT door (figure 10).

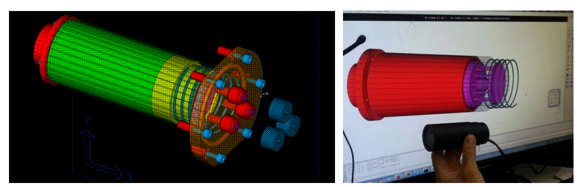

Figure 10. The design of the enclosure of the PMT

The external cylinder has been placed in the hole of the external frame. The final part of the cylinder allocate a groove for an o-ring that guarantee the insulation of the internal volume from the external environment (see figure11). At the end of the cylinder will be fixed the cookie with the fibers (see figure 11). The PMT is protected by the plastic internal enclosure. The enclosure will protect the PMT during the transportation and installation in the field, moreover gives the support for a spring pushing the PMT to the cookie (see figure **??**). The final part of the PMT enclosure design is the PMT door, that allows to close the PMT inside the module through six bolts installed into the external frame. The door,

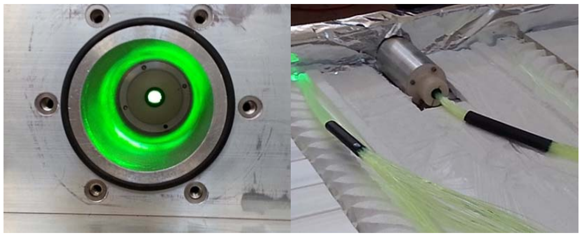

Figure 11. The Enclosure of the PMT

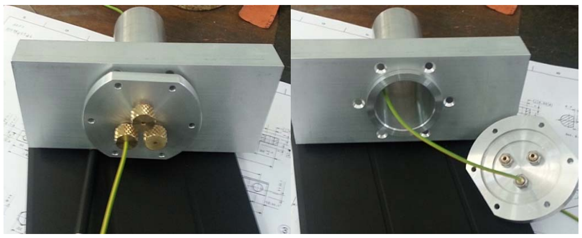

Figure 12. The PMT flange

named PMT-flange (see figure 12) also houses three passing point for the three cables coming out from the PMT (signal, HV and slow controls).

7. Test Measurements

In the first phase, we perform same tests in order to measure the MIP (Minimum Ionizing Particle). We use a small cosmic ray detector made by 4 scintillator tiles put into coincidence. Each tile has dimensions of 14.3×14.3×1.0 cm^3 and density of 1.032 g/cm^3 (BC-412). In each tile, the scintillation light is detected by two APDs (Avalanche Photo-Diodes) with 1 mm^2 sensitive area and it is collected through a wavelength-shifting (WLS) optical fiber of 1 mm diameter [3]. The flexibility of the fiber allows packing them in circular coils thus increasing the light collection efficiency over the plastic volume. Each detector is provided by an electronics frontend board on top that processes the signals from the two APDs and generates a coincidence LVDS signal.
We position this small detector under the LUNA module (see Fig. 13) and, using the NIM logic, we acquire the signal from the PMT in coincidence with the signal coming from this detector. In this way we select only Minimum Ionizing Particles passing the two detectors.
The data acquisition system is written in Labview; we acquire the signal from the PMT with an oscilloscope and the data are saved for later

Figure 13. Small cosmic ray detector made by 4 scintillator tiles put into coincidence positioned under LUNA module.

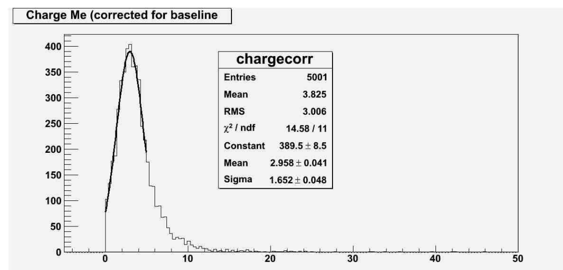

Figure 14. Charge distribution for MIP measured in the position A with HV = 1000 V for the PMT.

analysis.
We perform measurements changing the applied voltage to the PMT and putting the small detector in different positions under the LUNA module in order to cover all the detector area for checking bars and fibers uniformity.
Fig. 14-17 show the charge distribution in Me for the MIP measured at different voltage applied to the PMT. Considering the gain curve for the PMT previously measured, we can calculate the number of photoelectrons per MIP. Fig. 18 shows the measurements performed at different high voltage and put the small detector in different position respect to the LUNA module. Position A is a central position while position E is along the border of the detector vessel. The measurements performed show results compatible in the range of 18-22 photoelectrons for MIP.

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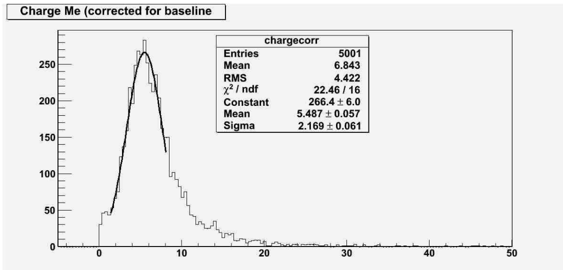

Figure 15. Charge distribution for MIP measured in the position A with HV = 1100 V for the PMT.

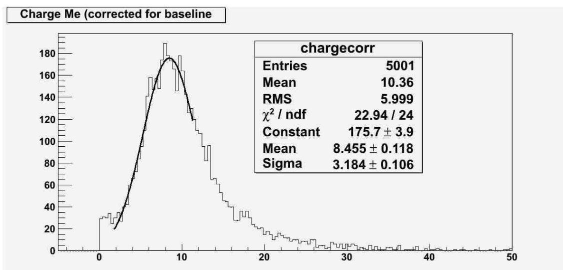

Figure 16. Charge distribution for MIP measured in the position A with HV = 1200 V for the PMT.

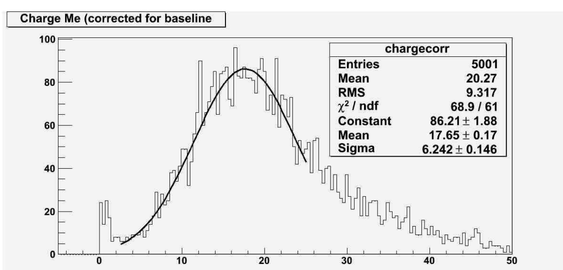

Figure 17. Charge distribution for MIP measured in the position A with HV = 1400 V for the PMT.

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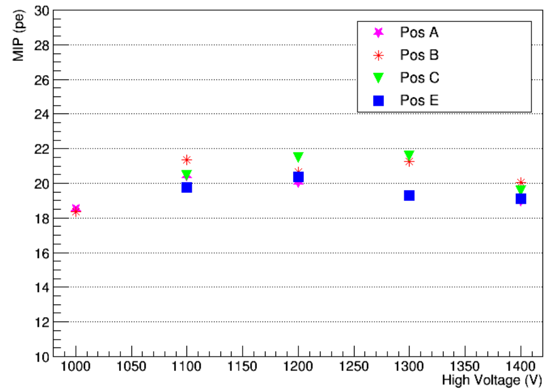

Figure 18. Number of photo-electrons per MIP at different PMT applied high voltage.